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AN APPLICATION OF CCD IN RSM TO OBTAIN OPTIMIZE TREATMENT OF ECCENTRIC-WEAVE FRICTION STIR WELDING BETWEEN POLYETHER-ETHER-KETONE POLYMER AND AA 6061-T6 WITH REINFORCED MULTIWALL CARBON NANOTUBES

L. PRABHU[1] & S. SATISH KUMAR[2]

[1]Research Scholar, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India

[2]Professor, Velammal Engineering College, Chennai, Tamil Nadu, India

ABSTRACT

The heat treatment of aluminium–PEEK (poly-ether-ether-ketone) alloy finds wide application in the aerospace and defence industry for its effective rate in strength to weight ratio and for good ductility. Friction Stir Welding (FSW) process (an emerging solid state joining process) is suitable for joining this alloy compared to fusion welding processes. The most significant process parameters are tool speed, feed rate, tool pin offset and axial force. By using central composite design and by employing Response Surface Methodology (RSM), regression models were developed to predict the responses. The mechanical properties, such as Ultimate Tensile Strength (UTS), impact strength and volumetric dispersion are considered as responses.

KEYWORDS: Poly-Ether-Ether-Ketone, AA6061, Friction, Stir, Welding, Multi, Wall, Carbon & Nanotubes

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Original Article

INTRODUCTION

Use of structural materials like PEEK and aluminium for its advantages such as high resistance to corrosion, excellent thermal and electrical conductivity provides effective results in engineering applications [1, 2]. Aluminium and PEEK as a composite structure creates some unsolvable problems such as oxidation and fragmental cracks [3,4].To overcome these problems, friction stir welding (FSW)process is an efficient welding process. This study aims to optimize the operating parameter of the friction stir welding of Aluminium and PEEK alloy by using a Central Composite Design (CCD), which is a Response Surface Methodology (RSM) of the Design-Expert® software. Friction Stir Welding (FSW) is a joining technique in solid state developed by TWI, Cambridge, in 1991 [5].

A non-consumable stirring tool with a shoulder and a stirring tool visco-plastic state of base metals joined leads to the creation of frictional heat between the base metal and the rotating tool. In this welding process, the phase metal displaced from one side to another side and mixed with each other to form a fusion of dissimilar metals [figure 1]. The response surface method has been conducted to achieve correlations of Al-PEEK friction stir welding in terms of ultimate tensile, impact strength and volumetric dispersion are optimized by using the resulting data from the response surface method in Design Expert software. Significant statistical quadratic polynomial for

this optimization process was obtained using regression analysis. To obtain effective inlet parameters (as creates effective impact on response values) on response variables, Central Composite Design (CCD) in Response Surface Method (RSM) was used.

MATERIALS AND METHODOLOGY

Eccentric Weave Friction Stir Welding (FSW)

Friction stir welding is a solid state joining process. Compared to other welding methods, FSW is a new joining welding process [14] especially to join two dissimilar metals [3, 4]. The working metals were joined by using non-consumable tool without melting the metals. Aluminium and PEEK were welded by the friction between the stirring tool and the metals. The heat produced near the rotating tool from this friction leads to softened state in the welding location. The following schematic diagram shows the working process of friction stir welding [figure 1].

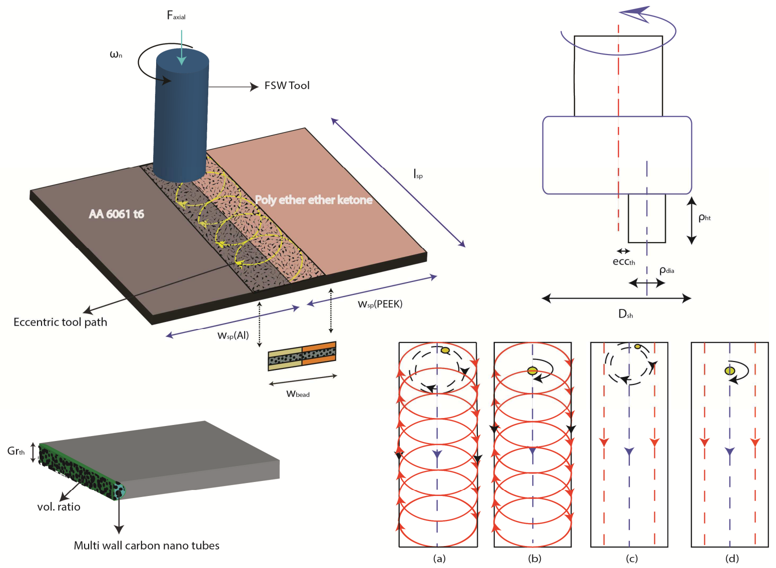


Figure 1: Mechanism of Eccentric Weave Friction Stirs Welding
(a) Eccentric Weld with Pin Offset (b) Eccentric Weld without Pin Offset
(c) Linear Weld with Pin Offset (d) Linear Welds without Pin Offset

Identification of Important Process Parameters

In the aluminium – PEEK friction stir welding, the primary process parameters are obtained in the way of their impact on the welding process of aluminium and PEEK. These process parameters were obtained as speed, feed rate, tool pin offset and axial force. These factors indicate as input parameters in the response surface methods. The operating process parameters are speed, feed rate, tool pin offset and axial force [Table.1].

Difficulties in Al-PEEK Welding Process

In the process of Al-PEEK welding, there are some difficulties are there such as melting, solidification, oxidation and variation in heat flow. To reduce these problems, friction stir welding was used. Compared to other fusion welding process, FSW process has shown effectiveness and improved mechanical properties [6-8]. Also the temperature variation in AL and PEEK cause difference of the heat flow in certain locations of the welded parts. The extensive thermo-chemical deformation induces dynamic recovery and welded microstructure refined by dynamic recrystallisation in friction stir welding process [9].

Response Surface Method (RSM)

Response surface methodology (RSM) is a collection of mathematical and statistical techniques used for analyzing the problems in this analyse, independent variables influence the responses. It provides a regression model that makes the relationship between the process parameters and response variables [10].It was used to develop a relationship between response variables y_a, and input variables, x_1, x_2,. . .,x_b. It is useful to reduce the cost in costly experiments effectively [11].

In general, the relationship between y and x_b is unknown but can be approximated by a low-degree polynomial model. This technique was introduced by Box and Wilson in 1951. They suggested second order degree polynomials to approximate the relationships, although there are other functional forms to apply RSM [12]. Response surface methodology was used to explore the relation between the feed rate, speed, tool pin offset and axial force as input variables and UTS, impact strength and volumetric dispersion as response variables. In these input parameters, major effective variables are to be obtained using RSM methodology. The following table shows the inlet parameter values (Table 1).

Table 1: Process Parameters and Working Range

Parameters	Working Range
Speed	1000 rpm to 1400 rpm
Feed rate	10 mm/min to 90 mm/min
Tool pin offset	0.4 mm to 2 mm
Axial force	9.5 KN to 19.5 KN

We employed central composite design to investigate the effect of input variables in the response values in friction stir welding process. CCD was used to generate second order (quadratic) polynomial model for UTS, impact strength and volumetric dispersion.

Optimization Process

The welding process of dissimilar metals as Al and PEEK employed by using central composite design in RSM method. By using RSM method, In Response Surface Method (RSM), Speed, feed rate, tool pin offset and axial force was entered as input variables. The major impact parameters on the response values were obtained in central composite method. The speed of the tool makes major impacts in the FSW process. By this tool speed, materials were removed in the welding area and removed materials were settled in the gap between tool pin and aluminium-PEEK alloy. The rotation of the tool pin stirring removes the materials in the welding surface. Mean values and standard deviation in response variables were tabulated below [Table 2]. By adjusting the input variables, the fine microstructure was obtained [5].

Table 2: Experimental Table for Optimization Process

Run	Factor 1 A: Speed rpm	Factor 2 B: Feed Rate mm/min	Factor 3 C: Tool Pin offset mm	Factor 4 D: Axial Force KN	Response 1 UTS MPa	Impact Strength J	Response 3 Volumetric Dispersion %
1	1100	30	0.8	17	186	8	70
2	1100	70	0.8	12	165	7.2	68
3	1200	50	1.2	14.5	190	8.6	74
4	1300	30	1.6	12	194	8.5	75
5	1200	50	1.2	9.5	185	7.9	6.9
6	1300	30	0.8	17	185	7.4	68
7	**1100**	**30**	**1.6**	**12**	**169**	**6.4**	**62**

Table 2: Contd.,							
8	1100	70	0.8	17	152	6.1	60
9	1200	50	2	14.5	185	7.8	72
10	**1200**	**50**	**1.2**	**14.5**	**180**	**7.6**	**69**
11	1200	50	0.4	14.5	190	8.3	71
12	1000	50	1.2	14.5	188	8.2	75
13	1300	70	0.8	12	156	6.7	65
14	**1200**	**50**	**1.2**	**14.5**	**178**	**7.2**	**61**
15	1300	30	1.6	17	192	8.5	73
16	1100	30	1.6	17	165	6.8	68
17	**1200**	**10**	**1.2**	**14.5**	**178**	**7.5**	**70**
18	1100	30	0.8	12	171	7	64
19	**1100**	**70**	**1.6**	**12**	**176**	**7.5**	**63**
20	1300	70	1.6	12	160	7.3	61
21	1200	50	1.2	14.5	160	7	58
22	1200	50	1.2	14.5	155	6.9	62
23	**1300**	**70**	**1.6**	**17**	**175**	**7.8**	**68**
24	1200	90	1.2	14.5	162	6.2	62
25	1200	50	1.2	19.5	186	8.2	71
26	**1100**	**70**	**1.6**	**17**	**170**	**8**	**63**
27	1400	50	1.2	14.5	179	7.9	70
28	**1300**	**30**	**0.8**	**12**	**169**	**7.3**	**63**
29	1200	50	1.2	14.5	188	7.9	71
30	1300	70	0.8	17	185	7.8	70

Table 3: Design Summary Table for Optimization Process

Design Summary					
File Version	10.0.1.0				
Study Type	Response Surface	**Subtype**	Randomized		
Design Type	Central Composite	**Runs**	30		
Design Model	Quadratic	**Blocks**	No Blocks	**Build Time (ms)**	79.00

	Factor Name	Units	Type	Subtype	Minimum	Maximum	Coded Values		Mean	Std. Dev.	
A	Speed	rpm	Numeric	Continuous	1000	1400	-1.000=1100	1.000=1300	1200	90.9718	
B	Feed rate	mm/min	Numeric	Continuous	10	90	-1.000=30	1.000=70	50	18.1944	
C	Tool pin offset	Mm	Numeric	Continuous	0.4	2	-1.000=0.8	1.000=1.6	1.2	0.363887	
D	Axial force	KN	Numeric	Continuous	9.5	19.5	-1.000=12	1.000=17	14.5	2.27429	
	Response Name	**Units**	**Obs**	**Analysis**	**Minimum**	**Maximum**	**Mean**	**Std. Dev.**	**Ratio**	**Trans**	**Model**
R1	UTS	MPa	30	Polynomial	152	194	175.8	12.2373	1.27632	None	RCubic
R2	Impact strength	Joules	30	Polynomial	6.1	8.6	7.51667	0.674707	1.40984	None	RCubic
R3	Volumetric dispersion	%	30	Polynomial	6.9	75	65.13	11.9987	10.8696	None	RQuadratic

Length of the Tool Travel

The length of the tool travel was calculated as,

Len $_{\text{tool travel}}$ = (P_{er} * length of the weld) / $P_{\text{in offset length}}$

The stirring area of eccentric movement = π*bead width*Pin offset length.

RESULTS AND DISCUSSIONS

Analyse of Variance

ANOVA (Analysis of Variance) is a collection of statistical models used to analyse the variation between the groups of parameter. Analysis of Al-PEEK friction stir welding was obtained by using ANOVA (analyse of variance) method. ANOVA was conducted for all responses and the results are presented in the following table [table. 4]. ANOVA analysis provides the results that all four independent variables of FSW welding process and their effective impacts on the response variables.

The Model F-value of 2.47 implies the model is significant. There is only a 4.99% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicates model terms are significant. In this case B, ABC is significant model terms. The ANOVA table presented the results analysis [table. 4 (a)]. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 4 (a): Analysis of Variance Table for UTS (Analysed)

Partial Sum of Squares - Type III						
Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob> F**	
Model	1908.94	7	272.71	2.47	0.0499	Significant
A-Speed	80.67	1	80.67	0.73	0.4024	
B-Feed rate	640.67	1	640.67	5.79	0.0249	
C-Tool pin offset	20.17	1	20.17	0.18	0.6736	
D-Axial force	112.67	1	112.67	1.02	0.3239	
AD	272.25	1	272.25	2.46	0.1310	
B^2	276.27	1	276.27	2.50	0.1283	
ABC	506.25	1	506.25	4.58	0.0438	
Residual	2433.86	22	110.63			
Lack of Fit	1381.03	17	81.24	0.39	0.9357	not significant
Pure Error	1052.83	5	210.57			
Cor Total	4342.80	29				

Std. Dev.	10.52	R-Squared	0.4396
Mean	175.80	Adj R-Squared	0.2612
C.V. %	5.98	Pred R-Squared	0.0796
PRESS	3997.26	Adeq Precision	7.265
-2 Log Likelihood	217.02	BIC	244.23
		AICc	239.87

The Model F-value of 2.47 implies the model is significant. There is only a 4.42% chance that an F-value this large could occur due to noise. Values of "Prob> F" less than 0.0500 indicate model terms are significant [table 4(b)].

Table 4(b): Analysis of Variance Table for Impact Strength (Analyzed)

Analysis of Variance Table [Partial Sum of Squares - Type III]						
Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob> F**	
Model	6.95	9	0.77	2.47	0.0442	Significant
A-Speed	0.57	1	0.57	1.82	0.1918	
B-Feed rate	0.70	1	0.70	2.24	0.1500	
C-Tool pin offset	0.22	1	0.22	0.71	0.4110	
D-Axial force	0.40	1	0.40	1.28	0.2711	

Table 4(b): Contd.,						
AB	0.46	1	0.46	1.46	0.2414	
AC	0.39	1	0.39	1.25	0.2769	
BC	0.33	1	0.33	1.06	0.3160	
B^2	1.85	1	1.85	5.92	0.0245	
ABC	2.03	1	2.03	6.50	0.0191	
Residual	6.25	20	0.31			
Lack of Fit	4.18	15	0.28	0.67	0.7484	not significant
Pure Error	2.07	5	0.41			
Cor Total	13.20	29				

Std. Dev.	0.56	R-Squared	0.5264
Mean	7.52	Adj R-Squared	0.3133
C.V. %	7.44	Pred R-Squared	-0.0353
PRESS	13.67	Adeq Precision	6.783
-2 Log Likelihood	38.09	BIC	72.10
		AICc	69.67

The ANOVA table presented the results analysis [table. 4 (c)]. The Model F-value of 2.92 implies the model is significant. There is only a 2.14% chance that an F-value this large could occur due to noise. Values of "Prob> F" less than 0.0500 indicates model terms are significant. In this case D, D^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

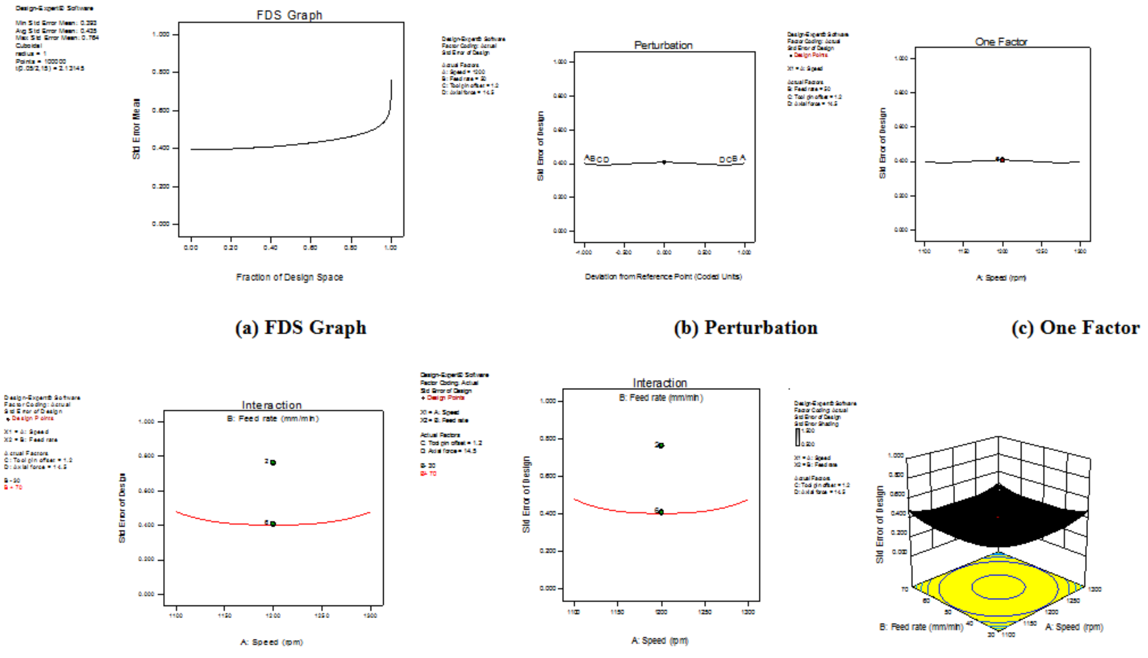
Table 4 (c): Analysis of Variance Table for Volumetric Dispersion (Analysed)

Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob> F**	
Model	2528.77	10	252.88	2.92	0.0214	Significant
A-Speed	9.38	1	9.38	0.11	0.7458	
B-Feed rate	70.04	1	70.04	0.81	0.3799	
C-Tool pin offset	2.04	1	2.04	0.024	0.8796	
D-Axial force	902.83	1	902.83	10.42	0.0044	
AC	18.06	1	18.06	0.21	0.6532	
BC	27.56	1	27.56	0.32	0.5794	
A^2	150.94	1	150.94	1.74	0.2026	
B^2	14.25	1	14.25	0.16	0.6896	
C^2	120.48	1	120.48	1.39	0.2529	
D^2	1001.19	1	1001.19	11.55	0.0030	
Residual	1646.33	19	86.65			
Lack of Fit	1443.50	14	103.11	2.54	0.1548	not significant
Pure Error	202.83	5	40.57			
Cor Total	4175.10	29				

Std. Dev.	9.31	R-Squared	0.6057
Mean	65.13	Adj R-Squared	0.3981
C.V. %	14.29	Pred R-Squared	-0.5798
PRESS	6595.83	Adeq Precision	8.350
-2 Log Likelihood	205.29	BIC	242.70
		AICc	241.96

Evaluation of Actual design

The 3-dimensional relationship was displayed in contour plots as two dimensions, with the factors, feed rate and speed. It reveals the potential relationship between the variables. For a better view of the response variables as UTS, impact strength and volumetric dispersion, three dimensional graph was obtained. The actual design process was evaluated by using the following figures 2[(a) – (f)]



(a) FDS Graph **(b) Perturbation** **(c) One Factor**

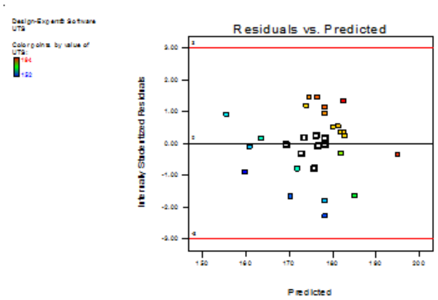
(d) Interaction **(e) Contour** **(f) 3D Surface**

Figure 2

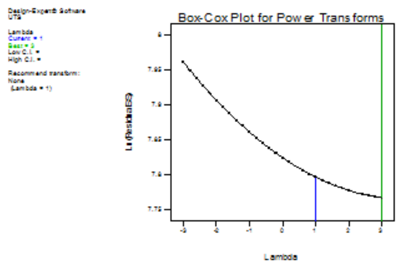
Analysis of Response Variables

Effect of Ultimate Tensile Strength on Process Parameters

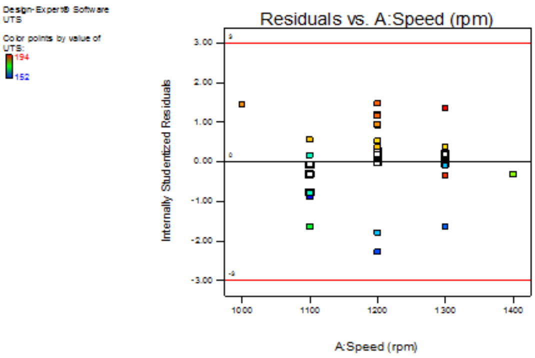
Diagnostics graphs explain the relationship between the predicted values and the actual values obtained from the optimization process [3(a) – 3(e)]. If the internally studentized residuals reach low values, the ultimate tensile strength attained low level. By this analysis, the ultimate tensile strength was attained by high residual points.



(a) Residuals vs Predicted



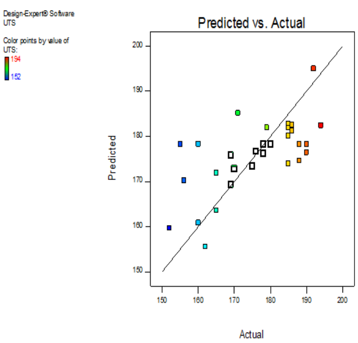
(b) Box-Cox plot



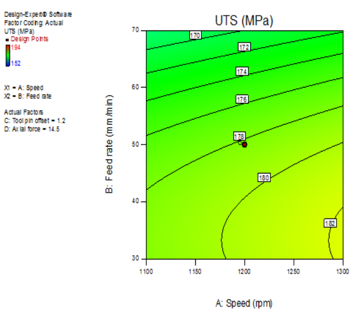
(c) Residuals vs Speed

Figure 3

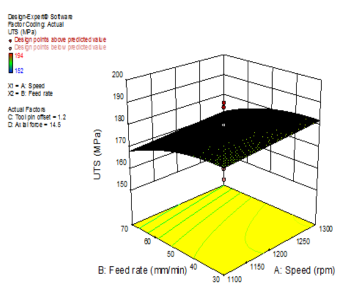
Contour graph explains the relationship of ultimate tensile strength with the parameters (speed, feed rate, tool pin offset and axial force).When we give feed rate 30 mm/min and speed near 1300 rpm, the effective UTS attained. For higher UTS value as near 194 MPa, tool pin offset to 1.6 mm and the axial force at 12 KN. When these values are at required state, they creates effective ultimate strength. By attaining this ultimate tensile strength value (194MPa), the welded material gains effective withstand capacity opposite to compressive strength. The mechanism behind the attained ultimate tensile strength explained as when the welding speed increases, the elongation of the welded metal increased. By increasing the tool speed, the welding process attained quickly [16]. Also, this welding speed was controlled with the tool speed and the axial force. This is because to control the temperature of the aluminium and PEEK metals below their melting range. So that the ultimate tensile strength obtained in friction stir welding. Also the predicted values were compared with actual values [figure 4 (b)].



(a) Predicted vs Actual



(b) Contour

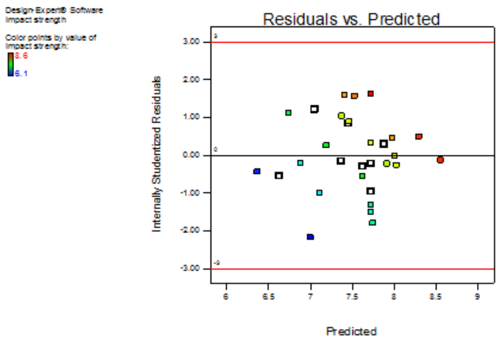


(c) 3D surface

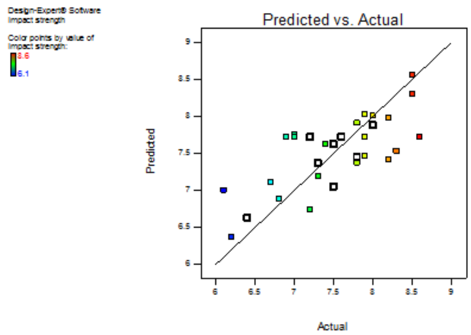
Figure 4

Effect of Impact Strength on Process Parameters

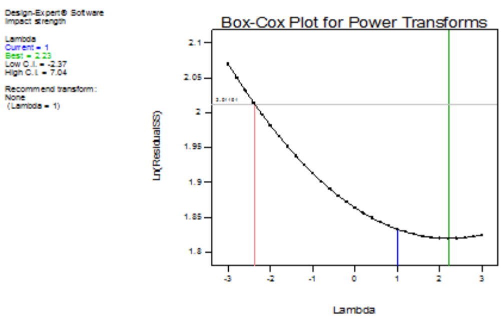
Impact strength gives the resistance to the dynamic load by stirring both the materials effectively. Following diagnostics graphs shows the relation between the predicted and actual values [5(a) – 5(d)]. The impact strength attained by the process of the strengthening welding process. Also the welding thickness plays an important role in the impact strength of the joined metal [17]. By increasing the tool speed, Al and PEEK stirred well at the calculated position of tool pin offset, the welding thickness increased to increase the impact strength. Tool pin offset plays a major role in stirring process as this value is set to 1.5 mm. The efficient impact value obtained from the optimization process was 8.6 Joules. To get this value, the process parameters were set to require state as speed was given as 1200 rpm and the feed rate was at 40 mm/min. An impact value 8.6 J gives greater resistance to the high loads in engineering applications. By this analysis, impact strength attained higher value, when the speed of the tool at minimum and the feed rate was at high range. Generally, this impact strength calculated as the ratio of impact absorption to test specimen cross-section.



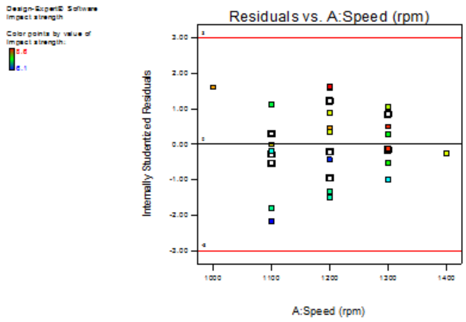
(a) Residuals vs Predicted



(b) Predicted vs Actual



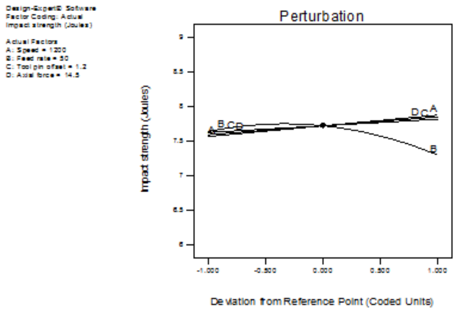
(c) Box-Cox for Power Transforms



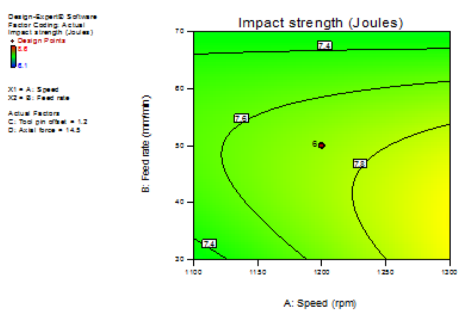
(d) Residuals vs Factor (Speed)

Figure 5

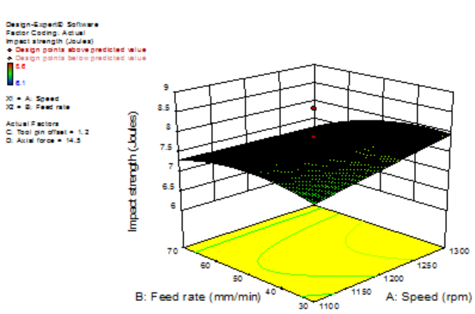
Tool pin plunge depth plays an important role in stirring process to attain maximum impact strength. By perfectly mixing the aluminium and PEEK metals, the impact strength increases efficiently. The following contour graph shows the relation among the input variables in impact strength [6 (b)]. 3D graph gives a better view of impact strength with the input parameters [6 (c)].



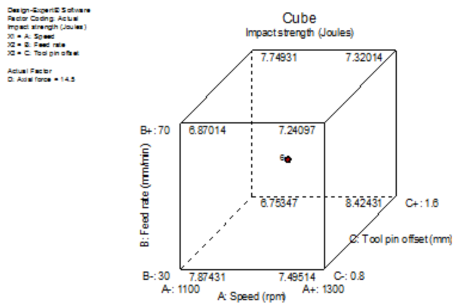
(a) Perturbation



(b) Contour Graph



(c) 3D Surface



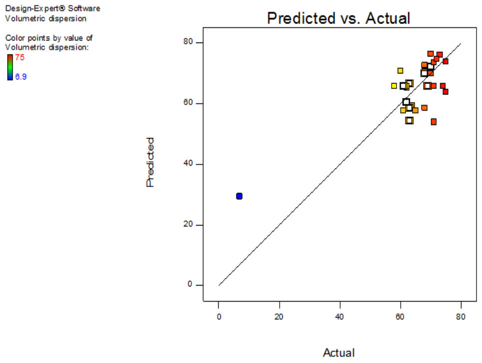
(d) Graph by Cube Model

Figure 6

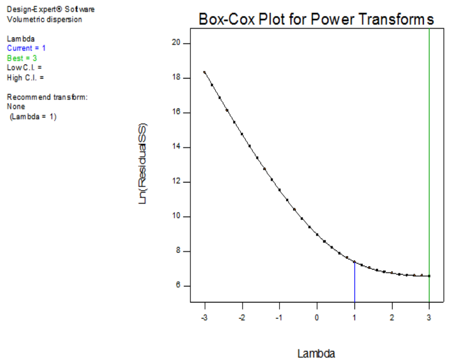
Effect of Volumetric Dispersion on Process Parameters

Volumetric dispersion is the response value for the distribution of aluminium and PEEK metals in the joining process. This volumetric dispersion value indicates the defect free microstructure without any lack of refill process [15]. It indicates the efficiency of the stirring process. Volumetric dispersion as 75 % indicates that the aluminium and PEEK were mixed excellently in the welding area. This high volumetric dispersion was obtained by low feed rate as 30 mm/min and the axial force at 14.5 KN. The mechanism behind the volumetric dispersion is, when the speed of the tool increases at moderate feed rate, both the metals heated. This heat is in the range below the thermal transiting level. At this rate, removed metals were stirred with the axial force. The axial thrust from the tool makes the stirred metals to join strongly.

The following diagnostics graph indicates the relation between the observed values with the actual values [figure 7 (a) – 7 (c)].A power transformation process related to the residual values indicated in the box-Cox plot graph [figure 7 (c)].

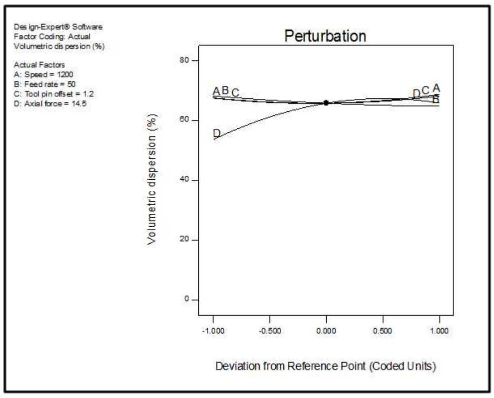


(a) Predicted vs Actual

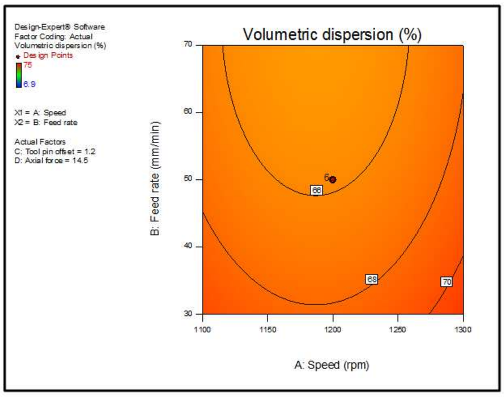


(b) Box-Cox Plot for Power Transforms

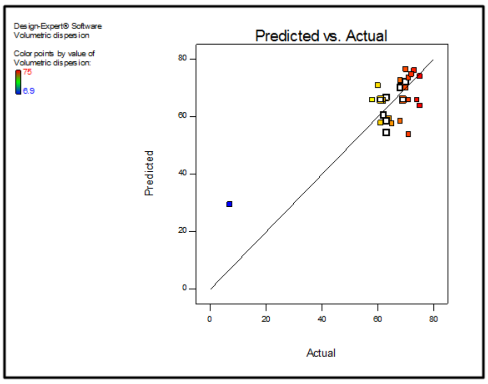
Figure 7



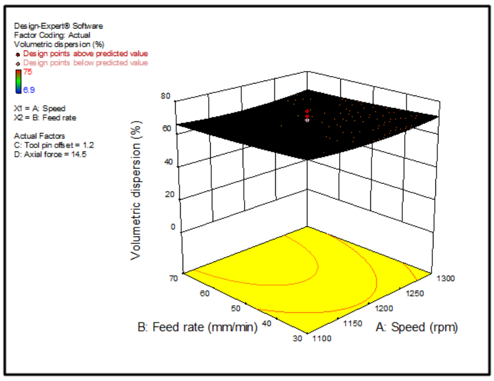
(a): Perturbation



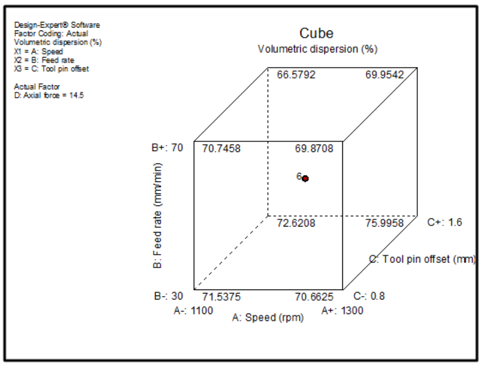
(b): Contour Graph



(c): Predicted vs Actual



(d): 3D Surface



(e): Graph by Cube Model

Figure 8

The above model graphs [figure 8 (a) -figure 8 (e)] shows the clearest view of response value (volumetric dispersion) obtained from the optimization process. Perturbation graph shows the deviation from the reference points as coded units with the volumetric dispersion [figure8 (a)]. The 3D model gives a clear view of the optimization for volumetric dispersion [figure 8(d)]. The graph model indicates the percentage of the volumetric dispersion related with input variables.

Effect of Process Parameters

Numerical Optimization

Following table shows the numerical optimization of the effectiveness process parameters on response variables [table. 5]. Also the lower and upper limits of the response variables indicated in this table.

Table 5: Numerical Optimization Table

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Speed	is in range	1100	1300	1	1	3
B:Feed rate	is in range	30	70	1	1	3
C:Tool pin offset	is in range	0.8	1.6	1	1	3
D:Axial force	is in range	12	17	1	1	3
UTS	None	152	194	1	1	3
Impact strength	None	6.1	8.6	1	1	3
Volumetric dispersion	None	6.9	75	1	1	3

Resulting Graphs of Numerical Optimization

The following graphs show the relationships between the response variables with the deviation from reference points observed in the numerical optimization process [figure 9 (a) -figure 9 (c)]. The perturbation graph model relates the residual values with the actual values [figure 9 (a)]. The contour models show the relation between the response variables as ultimate tensile strength, impact strength and the volumetric dispersion with the process or input variables [figure 9 (b)]. The cube model figures the observed values of responsible variables for the operating parameters [figure 9 (c)].

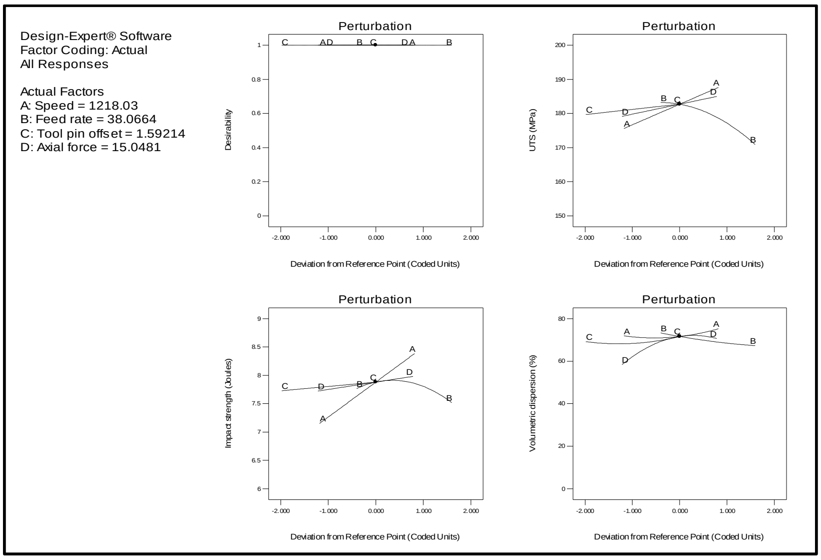


Figure 9 (a): Perturbation Graph

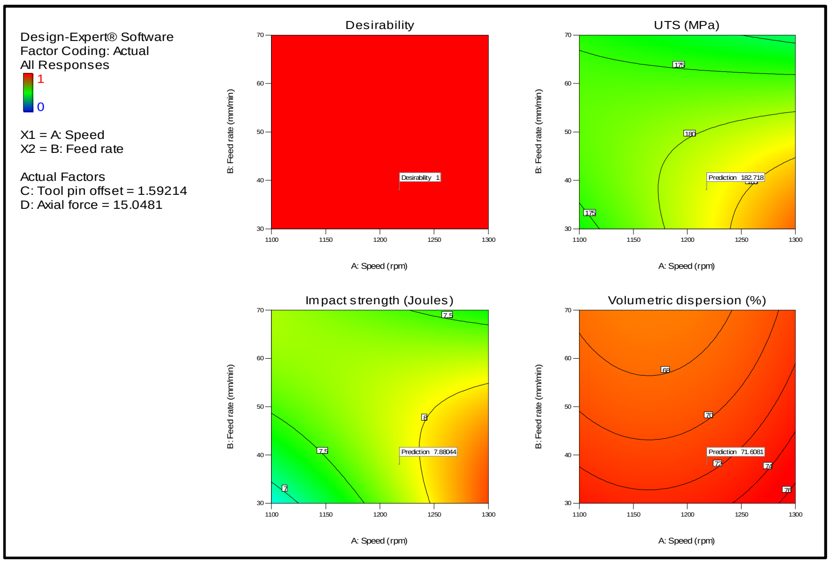


Figure 9 (b): Contour Graph

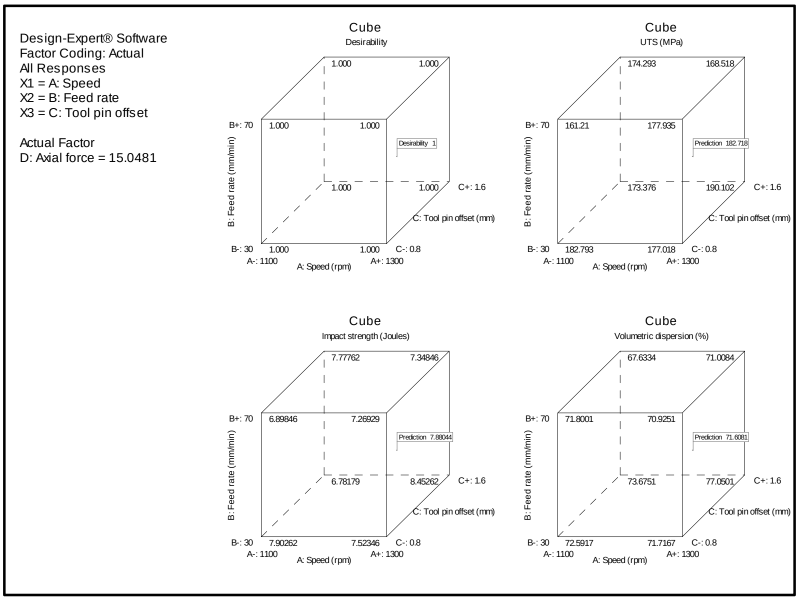


Figure 9 (c): Cube Model

Graphical Optimization

The overlay plot graph shows the graphical optimization model to the operating parameters [figure 10]. It shows the relation between the input variables by comparing with the actual values.

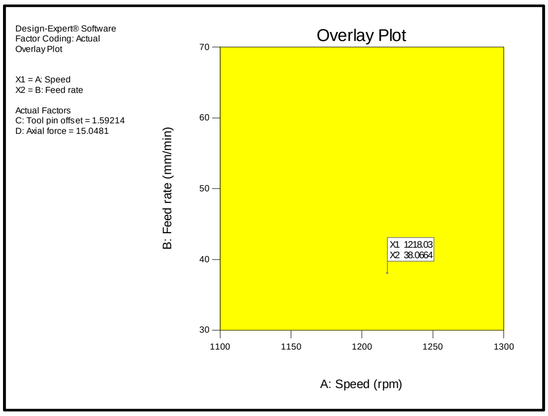


Figure 10: Contour Graph

Post Analysis

By using central composite design in response surface method, the impact on response variables were obtained and the points predicted in this method tabulated below [table.6]. It shows the standard deviation in the response variables. Also the confirmation of this predicted values were tabulated [table.7]. By the observed points in this optimization process in RSM method, we can find the effective values of input parameters to get an efficient response variables. These values used to get the effective joining process of Aluminium and PEEK metals by friction stir welding process. The coefficient table shows the measured value for the output characteristics or response parameters [table. 8]. These measurement values summarize the coefficient value for the joining of two dissimilar metals (Al and PEEK).

Table 6: Point Prediction Table

Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	Speed	1299.19	1100.00	1300.00	0.000	Actual
B	Feed rate	68.21	30.00	70.00	0.000	Actual
C	Tool pin offset	1.52	0.80	1.60	0.000	Actual
D	Axial force	14.68	12.00	17.00	0.000	Actual

	Predicted				CI for Mean		99% of Population	
Response	Mean	Median[1]	Observed Std Dev	SE Mean	95% CI low	95% CI high	95% TI low	95% TI high
UTS	169.953	169.953	-10.5181	4.31324	161.008	178.898	126.369	213.537
Impact strength	7.41127	7.41127	-0.559113	0.301446	6.78246	8.04007	4.93611	9.88642
Volumetric dispersion	69.6568	69.6568	-9.30854	4.48323	60.2733	79.0403	29.046	110.267

Table 7: Confirmation Report Table

Two-sided	Confidence =95%		n =1			
Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	Speed	1299.19	1100.00	1300.00	0.000	Actual
B	Feed rate	68.21	30.00	70.00	0.000	Actual
C	Tool pin offset	1.52	0.80	1.60	0.000	Actual
D	Axial force	14.68	12.00	17.00	0.000	Actual

Response	Predicted Mean	Predicted Median[1]	Observed StdDev	n	SE Pred	95% PI low	Data Mean 95% PI high
UTS	169.953	169.953	-10.5181	1	11.37	146.38	-193.53
Impact strength	7.41127	7.41127	-0.559113	1	0.64	6.09	-8.74
Volumetric dispersion	69.6568	69.6568	-9.30854	1	10.33	48.03	-91.28

Table 8: Co-efficient Table

Response	Intercept	A	B	C	D	AB	AC	AD	BC	A^2	B^2	C^2	D^2	ABC
UTS	178.278	1.83333	-5.16667	0.916667	2.16667			4.125			-3.09722			-5.625
p		0.4024	0.0249	0.6736	0.3239			0.1310			0.1283			0.0438
Impact strength	7.71944	0.154167	-0.170833	0.0958333	0.129167	-0.16875	0.15625		0.14375		-0.253472			-0.35625
p		0.1918	0.1500	0.4110	0.2711	0.2414	0.2769		0.3160		0.0245			0.0191
Volumetric dispersion	65.8333	0.625	-1.70833	0.291667	6.13333		1.0625		-1.3125	2.34583	0.720833	2.09583	-6.04167	
p		0.7458	0.3799	0.8796	0.0044		0.6532		0.5794	0.2026	0.6896	0.2529	0.0030	
Legend		p <.01	.01<=p<.05	.05<=p<.10	p >=.10									

CONCLUSIONS

An optimization process was conducted to examine and improve the joining process of aluminium and PEEK alloy using friction stir welding (FSW) in Response Surface Method (RSM). By the absorption of response variables, UTS, the capacity of a joined Al-PEEK metal increased efficiently to withstand against the compressive strength. Impact strength values indicate the effective resistance capacity of the welded Al-PEEK metal to the dynamic loads. Also the resultant volumetric dispersion variables show that the distribution of the metals in the stirring process to attain maximum strength. The overall optimization process indicates that the friction stir welding process provides the fine macro and microstructural surfaces. Moreover, it was found that effective joining of Al-PEEK was achieved by varying input variables. When the feed rate increases, the ultimate tensile strength increases.

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